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REPORT NO. 20-132

MODIFICATION OF SERGEANT MAINTENANCE CONCEPT FOR OPTIMUM ALLOCATION OF CAPABILITIES

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MODIFICATION OF SERGEANT MAINTENANCE CONCEPT FOR OPTIMUM ALLOCATION OF CAPABILITIES

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ABSTRACT

Results of statistical studies are applied to an objective review of *Sergeant* maintenance and logistical support with respect to electronic items. Alterations in the *Sergeant* maintenance concept suggested by the Ordnance Corps are analyzed. Recommendations for modification of the concept are presented, in the areas of the allocation of test stations and on-vehicle material, of storage-reliability evaluation, and of checkout policy.

I. INTRODUCTION

This report presents as objective as possible a review of the maintenance and logistical support (considering electronic items only) required to maintain *Sergeant* in the field in a high state of operability under all conditions, with a view to making recommendations as to the optimum allocation of support capabilities to achieve such a state of operability.

Specifically, it offers recommendations, based on statistical studies, for certain alterations to be made in the *Sergeant* maintenance concept.[1] In addition, and to an extent incidentally, it is intended to clarify some published and implicit aspects of the concept, and to discuss certain alterations proposed by the Ordnance Corps in Fall 1958.

[1] Salem, G. M., *The Sergeant Weapons System Maintenance Concept*, Report No. 20-130. Jet Propulsion Laboratory, Pasadena, California, July 14, 1959 (Secret).

A. Sergeant in the Field

The *Sergeant* weapons system will be deployed in active service by battalions. The Field Artillery Missile Battalion—*Sergeant* most probably will be composed of one Firing Battery, having two Firing Platoons each with one launching station, and a Headquarters and Service Battery (Fig. 1). The Battalion will usually be under tactical and administrative control of the field Army or Corps commander as a general support weapon. The typical field Army might have as many as three *Sergeant* Battalions.

The *Sergeant* has been designed for package replacement maintenance. A user-maintenance facility, the organizational maintenance test station (OMTS), and an Ordnance-maintenance facility, the field maintenance test station (FMTS), have been designed as integral parts of the *Sergeant* weapons system. In the past the Jet Propulsion Laboratory has proposed a maintenance support plan

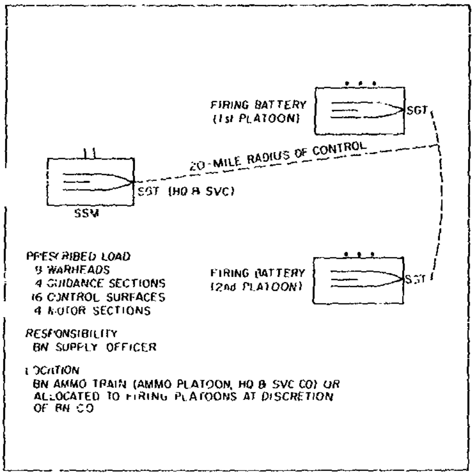

Fig. 1. *Sergeant* Battalion Deployment

which allocates one OMTS to each Firing Platoon in the *Sergeant* Battalion, one FMTS to each Ordnance Direct-Support unit, and one FMTS to each Ordnance Heavy Maintenance support facility.

Each of the major items of ground equipment in the weapons system is designed to carry 100% on-vehicle spares for its own electronic operating equipment. In addition, the OMTS was designed to be able to carry 200% missile-guidance spares, and the FMTS was designed to be used in conjunction with 100% assembly and subassembly organic-stock spares for all major items.

B. Maintenance-Concept Alterations Proposed by Ordnance Corps

In Fall 1958 the Ordnance Corps requested that this Laboratory examine the effects upon *Sergeant* operability and maintainability of several proposed alterations to the basic maintenance philosophy of the *Sergeant* weapons system. The alterations proposed, as they fall within the scope of this discussion, are listed below.

1. Removal of all electronic operating-assembly spares from the launching station.
2. Removal of all electronic operating-assembly and missile-guidance-assembly spares from the OMTS.
3. Removal of all electronic assembly and subassembly spares from the FMTS.

These measures would serve to reduce the initial cost of the *Sergeant* weapons system by a considerable amount, although it should be noted that the end cost would not be substantially different. However, the scope and effectiveness of the maintenance support would be severely limited by such changes.

It is considered, therefore, that the *Sergeant* maintenance plan as altered by the suggestions listed will not provide adequate support for *Sergeant*; further, it will not be in harmony with the maintenance philosophy already designed into the weapons system.

The basic area of contention between the Jet Propulsion Laboratory and the Ordnance Corps lies in the allocation of on-vehicle spares (on-vehicle material or OVM) to the major items of ground equipment. This problem is taken up in some detail in Section IV of this Report.

II. SERGEANT OPERATIONS AND SUPPORT

The tactical and technical requirements which *Sergeant* has been designed to meet are set forth in the *Sergeant* Military Characteristics.[2] The maintenance and support philosophy[1] is part of this design. However, some alternatives in the maintenance plan may be considered and evaluated in terms of the Military Characteristics.

A. Modes of Operation

The *Sergeant* Battalion will function in two radically different modes: the peacetime mode, and the wartime (or immediate-threat-of-war) mode. In peacetime the emphasis is on training and on maintaining readiness in the prescribed load of missiles and in the major items for possible war. In war or immediate threat of war, *Sergeant* will be able to maintain a very high degree of readiness in the prescribed load and in the launching station and to deliver without delay a high rate of fire. In addition, the Firing Platoons will be capable of performing "shoot and scoot" missions which involve rapid emplacement, firing, and displacement.

All of these capabilities place direct requirements upon the maintenance-support facilities associated with *Sergeant*. Any maintenance-support plan proposed for *Sergeant* must be able to meet all of these requirements efficiently and reliably. It must be able to make the transition from peacetime to wartime operations rapidly and with a minimum of alteration.

B. Statistical Visualization of Reliability

In order to evaluate a way of providing maintenance support, it is first important to understand three closely related concepts: reliability, reliability decay, and rate of reliability decay.

Reliability, as the concept is used in this discussion, is the probability that the missile will fire on time after it is removed from its containers and assembled on the launcher. Reliability decay is based on the opposite of reliability, that is, the probability that the missile will not fire on time. This probability is equivalent to the probability that a failure will be detected (assuming that any failure will be detected and will halt or delay firing). The rate of reliability decay is the time-rate of increase of this probability after a checkout of the missile. Thus, to evaluate reliability and the related concepts requires the statistical model describing the occurrence of failures.

Failures in the *Sergeant* weapons system are described by two models. One model involves wear. It has no bearing on the terms being discussed here; it is explained in Section IIIA. The other model postulates that failures occur by chance in any interval of time after a checkout, and that there is no way of knowing that a failure has or has not occurred, except an attempt to check out or fire the missile.

This second model describing *Sergeant* preflight failures is based on the Poisson distribution of chance events and is best described in terms of a game of chance. It is as though in each minute that passes after a checkout, a dice player rolls a pair of dice. The rules of the game are such that each roll of the dice is a new game. If the player rolls a number other than a given one (say 7), the minute passes uneventfully. If he rolls the 7, a failure occurs. The player is not allowed to see the outcome of the roll but there is a scorekeeper who does keep track of the outcomes. At any time the player can ask the scorekeeper whether or not he has thrown a 7 since the last time he asked. Obviously, the longer he waits before asking, the more likely it is that he has thrown a 7.

The play of the dice player represents the progress of time in which chance failures occur. The scorekeeper, keeping track of reliability decay, corresponds roughly to the checkout equipment. The player asking the scorekeeper whether he has rolled 7 is analogous to a checkout or a firing attempt. The number 7, with the maximum probability of occurrence in the game, corresponds to a fairly high chance of failure; if the number on the dice which corresponds to a failure is 2, or 12, with minimum probability of occurrence, this corresponds to a low chance of failure. What the number is corresponds to the rate of reliability decay.

Suppose the player wishes to maintain a high confidence that he has not rolled a seven. Since sevens occur

[2] *Development, Test, and Demonstration of the Sergeant Field Artillery Guided Missile System*, Technical Requirements No. 19, Revision No. 8. Research and Development Division, Redstone Arsenal, Huntsville, Alabama, June 3, 1957 (Secret).

quite frequently, he must ask the scorekeeper fairly often. If he is trying to maintain a certain confidence that he has not rolled a 2, he need not ask so often. Also if the player will accept a low confidence that he has not rolled 7, he need not ask so often.

In missile maintenance terms, suppose a high reliability standard is coupled with a high rate of reliability decay. Checkouts must be scheduled quite often. If the rate of decay, or instantaneous probability of component failure, is quite low, checkouts need not occur so often. Also, if a lower reliability standard is accepted with a high failure probability, checkouts need not be made so often.

Thus it is evident that given the rate of reliability decay, a balance can be struck between the level of reliability maintained and the length of time between checkouts to arrive at a maintenance plan best suited to system requirements.

C. Methods of Supporting Sergeant

The two maintenance-support methods under consideration differ in the allocation of the major user test-equipment item. The first alternative places this support at Battalion level; in the second alternative, the Firing Platoon possesses its own testing station. The two checkout and support systems are shown in Fig. 2.

1. Battalion-support method. Under the first scheme, the *Sergeant* FAM Battalion would have only one OMTS, located at the Headquarters and Service Battery. Peacetime readiness of the prescribed load would be assured by periodic checkout of the missiles in the Battalion prescribed load by the OMTS. The ability of this station to perform its function depends on the location of the prescribed load and the time-between-checkouts requirement. Thus if the complete prescribed load were kept at the Headquarters and Service Company, the OMTS could easily perform its task no matter how short the time between checkouts. If the load is scattered among the Firing Platoons, and the Firing Platoons are as much as 20 miles from Battalion Headquarters and 40 miles from each other, the job of the OMTS becomes slightly more difficult; its dependence upon the time between checkouts is greater. As an absurd example, if it were required to check out the complete prescribed load twice a day to maintain a certain reliability it would be impossible for one OMTS to handle the job.

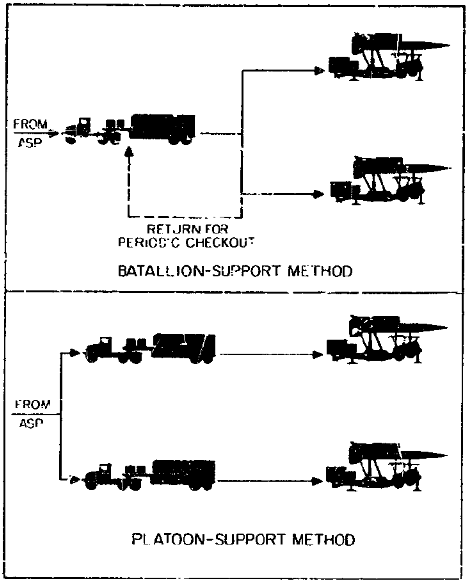

Fig. 2. Missile Checkouts under Two Support Methods

The training mission of the OMTS in this support configuration could easily be performed by the best training of all, on-the-job-training. The training mission of the other elements in the Battalion are unaffected by the disposition of the OMTS.

The ability of the OMTS to maintain the prescribed load in a heightened state of readiness in wartime or in the immediate threat of war again depends on the rate of decay in reliability.

The ability of a single OMTS (with 100% spares) adequately to support an average rate of fire as high as 12 rounds per day per Battalion has been demonstrated by simulation techniques on an IBM-704 computer.

The wartime use of the OMTS in the *Sergeant* Battalion would be restricted to maintenance of the prescribed load of missiles. High firing rates would be supported by the Army Ammunition Supply Point. That is, the Firing Platoons would draw checked-out missiles from the Supply Point and fire them without any checkout additional to that provided by the launching station itself. It should be noted at this point that the launching-station checkout will detect every type of discrete missile failure which the OMTS will detect; that is, the launching station will reject every bad missile that the OMTS will. The only difference is that the launching station isolates malfunctions to a particular major assembly such as warhead, motor, guidance section, or fins, while the OMTS isolates malfunctions to the assembly level.

Clearly, the procedure of drawing checked-out missiles from supply and firing them without OMTS checkout depends for success on a rate of reliability decay which is low enough that the missile will still have an acceptable probability of firing on time when placed on the launcher (after some nominal delay which might, for example, represent the time required to transport the round from the Ammunition Supply Point to the launch site). If the rate of decay in reliability were so high that the probability of firing on time would have fallen below the acceptable level before the round had arrived at the launch site, then an OMTS checkout prior to assembly of the missile on the launcher would be required.

The support plan in which the Firing Platoon draws checked-out missiles from the Supply Point and fires them provides that "shoot and scoot" missions would be performed without the immediate support of an OMTS. Indeed, if an OMTS checkout of the missile is required immediately before firing in the "shoot and scoot" operation, the minimum time required for the particular firing mission is doubled.

2. *Platoon-support method.* The second alternative provides that each Firing Platoon have its own OMTS. In the maintenance plan designed by this Laboratory, each OMTS is complete with 100% OVM. The Ordnance-altered plan calls for the elimination of all OMTS spares carried as OVM. With regard to peacetime maintenance of the prescribed load, either of these systems will perform adequately. As has been mentioned earlier, there exists a remote possibility that the platoon-support method would be the only feasible plan to maintain a level of readiness, if the rate of decay in reliability after checkout were rapid enough so that very frequent checkouts were required to maintain the level of readiness. Again it should be emphasized that the possibility is remote. Peacetime training requirements are fulfilled adequately by either system.

The wartime capability of these systems is complicated by the problem of OVM, which will be discussed in Section IV. The platoon-support method (which is substantially the maintenance plan as described in the Maintenance Concept[1]) performs satisfactorily, but extravagantly, in the wartime situations. This is especially true if the rate of reliability decay is low; the result is expensive equipment tied up with little or nothing to do. It is concluded that the system with two OMTS's and no OVM will be unable to perform adequately any of its missions in wartime.

III. STORAGE OF MISSILE SECTIONS

It seems clear from the preceding discussion that the key to the problem of whether to have one OMTS per Battalion or one OMTS per Firing Platoon is the rate of decay in reliability after checkout. Since this rate of decay in reliability after checkout or storage reliability is so important it will be discussed in detail. First of all storage reliability is defined as the reliability of the missile as a function of time from last checkout.

It is necessary to distinguish three storage environments which the *Sergeant* is likely to encounter. In all cases the missile sections are assumed to be stored in their sealed containers.

1. *Passive Storage* is open storage or storage in warehouses in which the missile sections are subjected to little or no shock and vibration.

2. *Transport Storage* is any and all handling and transport undergone by the missile sections in their sealed containers between the last checkout at the factory and the final placement of the containers on the specially designed Battalion transport trailers in the field.

3. *Field Storage* is the carrying around of the missile sections on the transport trailers as part of the Battalion prescribed load.

The storage Military Characteristic[2] (Section 1.2.11.1) presumably refers to the combination of passive storage and transport storage. However, the focus of interest in this treatment is field storage. Reliability during field storage decreases less than during the combination of passive and transport storage, according to the experience of this Laboratory with the potentially rough treatment which can be meted out to the missile sections during such operations as loading and unloading at docks and warehouses, communication-zone truck and rail transport, or constant handling in the Ammunition Supply Point.

A. Field-Storage Reliability

The reliability or readiness of a missile in the prescribed load during field storage is measured by the probability that the missile will fire successfully at the time it is removed from storage. This reliability is a function of time since the last checkout. The reliability of a missile diminishes as time increases after a checkout. Each checkout brings the reliability of the missile almost up to the level it had at the time of the previous checkout. The word "almost" is inserted because some components in the missile are subject to wear, and each checkout causes a certain amount of wear, which decreases reliability. The number of checkouts per unit time or, inversely, the time between checkouts, required to maintain a reliability greater than or equal to a given level depends on the rate at which reliability drops off as a function of time from last checkout. The total number of checkouts which can be performed depends on the rate at which wear decreases the maximum achievable reliability; thus there is a point at which the reliability of the missile immediately after a checkout will be less than the required level because some assemblies have reached a point in their lifetimes at which the probability of a failure increases sharply.

Figure 3 presents graphically the effect of wear on maximum achievable reliability and on time between checkouts.

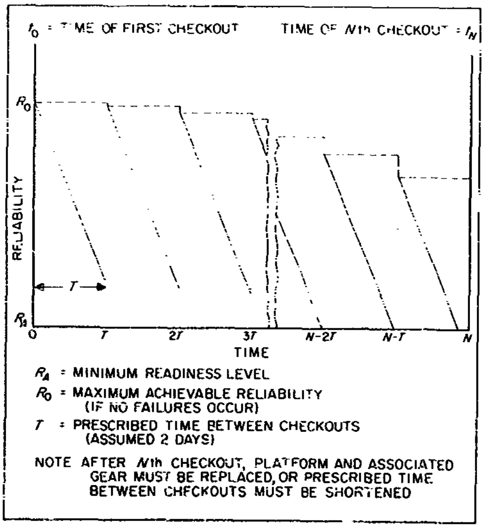

Fig. 3. Effect of Wear on Maximum Achievable Reliability and on Time between Checkouts

The steep parallel curves represent the time decay in reliability after checkout. The dotted verticals represent the restorative effect of the checkout. If there were no wear associated with a checkout, each additional checkout would bring the reliability of the missile up to R_o. The time between checks, T, would be the time required for the decay curve to pass through R_1. The stepped, broken-line curve represents the maximum achievable reliability. Each succeeding checkout decreases the maximum achievable reliability because of wear. This has the effect of causing the decay curve to pass through R_1 sooner than it would have otherwise. It is obvious from the Figure that T is a function of the number of checkouts. In practice, some constant T would probably be chosen so that at first the checkouts would be performed slightly more often than necessary. As the missile approached the time when the items subject to wear should be replaced, the checkouts would be performed slightly less often than necessary to maintain the minimum readiness level. This condition can be seen in the Figure by noticing the relationship between where the decay curves pass through R_1 and where the dotted lines representing checkouts pass through R. Towards the right side of the graph the curves are intercepting the R_1 line as much as ¾ day ahead of the next checkout time.

Referring to Fig 4, a missile whose reliability in field storage is as poor as at $T_{95\%} = 6$ days (the middle curve) could easily be maintained at an acceptable level of readiness by a *Sergeant* FAM Battalion with a single OMTS. This six-day time between checkouts would be sufficient to allow the type of wartime procedure envisioned for the single-station Battalion. The curve labeled $T_{95\%} = 50$ represents the engineering judgment of the Jet Propulsion Laboratory concerning the field storage reliability of *Sergeant*. A single OMTS per Battalion is more than adequate under these circumstances. The 2-day case represents the very improbable conditions which might lead to assigning one OMTS per Firing Platoon.

However, it is the opinion of this Laboratory that should this highly unlikely situation occur, the cost of the second OMTS per Battalion would be better spent in product improvement.

B. Continuing Experimental Program

Starting with the first Engineering-Model *Sergeant* round, a policy will be established of taking the missile

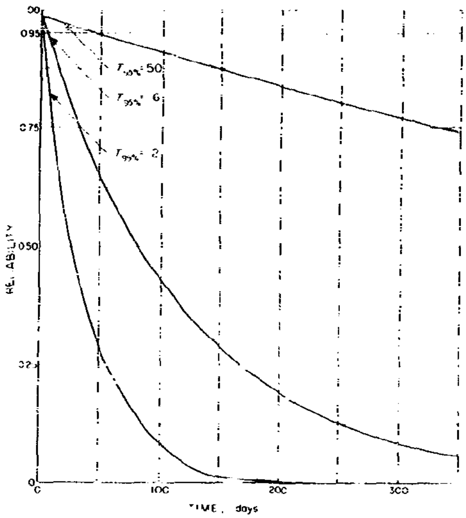

Fig. 4. Field-Storage Reliability

from whatever storage and handling it has experienced since its last checkout at the factory, placing it directly on the launching station without further checkout by the OMTS, and attempting to complete a mock firing. The storage and handling environments undergone by the missiles will be controlled to whatever extent is practicable, in order to obtain results based on a spectrum of likely handling and storage environments.

Records will be kept of the environment experienced by each missile and its performance on the launcher. After the mock firing each missile will be checked out by the OMTS, and records will be kept of the results of these checkouts. Missiles which fail to complete the mock firing will be repaired by the OMTS, and records will be kept of the repairs. (The same missiles will then be fired in the EM firings.) These records will provide a preliminary estimate of the reliability degradations of *Sergeant* in all three storage modes. Further the laboratory will recommend that the experiment be continued through the Engineer-User Evaluation, the User Evaluation, and the field life of the weapons system, or until the Ordnance Corps has built up a level of confidence satisfactory to themselves in a value for the rate of decay of reliability for *Sergeant* in field and passive storage.

IV. SPARE-PARTS STOCKAGE

Studies have shown that in order to maintain a high level of operability, a complex system must have either on-vehicle spares or a highly reliable spares supply line with a delay time on the order of a few hours.

A. On-Vehicle Material

It is impossible to guarantee such a supply line as that mentioned above. Therefore in order to maintain a high level of operability a complex system must have OVM. However, in the *Sergeant* weapon system the requirement for a high level of operability varies with the major item considered.

1. Launching station. The highest possible level of operability is required of the launching station at all times, since it is directly involved in determining the combat payoff of a missile firing. In addition, tactical conditions would keep the launching station isolated from repair and parts-supply facilities much of the time. *Thus in order to maintain combat integrity it must have 100% OVM at all times.*

2. *OMTS.* In peacetime it is not absolutely necessary that the OMTS have OVM. Since its primary mission is to maintain the readiness of the prescribed load, the OMTS could be deadlined for spares for as long as the time required between checkouts. This condition would not seriously impair the readiness capability of the weapon system.

In wartime, however, the OMTS must have OVM to support high firing rates and to maintain the heightened readiness capability. The results of statistical studies on this specific phase of the OVM problem are included to illustrate the point. In Fig. 5, the vertical scale represents a measure of the ability of a single OMTS to check out missiles fast enough to support the firing rates marked off on the horizontal scale. Each curve shows the performance of the OMTS for a different delay time for replacement of a failed OMTS assembly. Curves A, B, and C represent the performance of the OMTS with no OVM and with delay times of 2, 8, and 40 hours respectively. Curve D demonstrates the performance of the OMTS with a 40-hour delay time and 100% OVM. Figure 6 amplifies this contrast, showing that an OMTS with 100% OVM and a 40-hour delay time performs as well as an

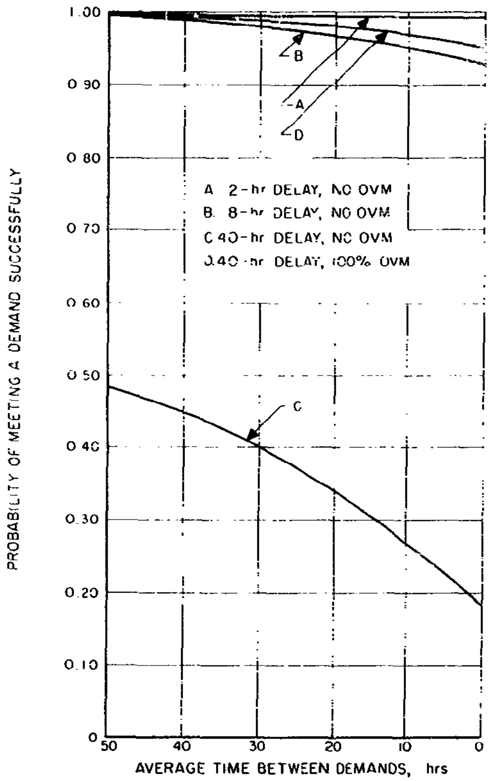

Fig. 5. Effect of Spares on Checkout Reliability

OMTS with no spares and a 7- or 8-hour wait time. Experienced military personnel will probably recall not infrequent occasions in wartime when a supply line with a 40-hour delay was considered marvelously fast.

Since the OMTS must have OVM in wartime, and since the OMTS must be capable of rapid transition from peacetime to wartime status, is seems reasonable to require that the OMTS be issued with OVM in peacetime, rather than issuing it without OVM, but with the OVM stored close enough to insure rapid changeover to wartime status

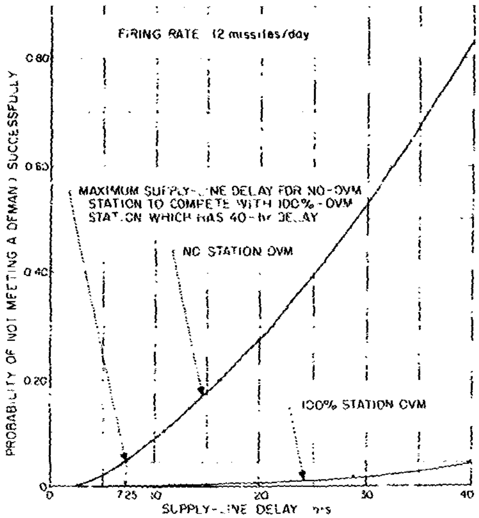

Fig. 6. Requirement Placed on Supply Line by Checkout Unreliability

B. Selected Spares

The principle of stocking only selected spares to support a complex system is certainly a reasonable one. It is clear that in general the purchase of selected spares represents the optimum allocation of money for spares. However, the design of the *Sergeant* is such that great care must be taken in making decisions as to which spares will be selected. Any arbitrary-decision rule such as 'spend 15% of the total cost of operating equipment on spares or 'stock the three least reliable assemblies in each major item,' etc. will in many cases result in serious impairment of the over-all capability of the major item.

1. Missile. In the case of the missile, a policy of selected stockage of spares is mandatory. Some of the assemblies in the missile are subject to mechanical wear, as has been discussed previously. Toward the end of the 'checkout' life of a missile, repair of such items becomes more and more frequent. Also, a few of the missile assemblies are as much as a factor of 10 less reliable than any of the other assemblies, independent of the 'checkout' life. These assemblies can be expected to fail more frequently than the others. Unfortunately, little saving in money can be expected from a selected-spares policy for the missile, since the three most unreliable assemblies, the most likely to suffer wear, represent approximately 85% of the total cost of missile assemblies.

2. OMTS. Selection of spares for the OMTS is complicated by two factors. First, the OMTS required spares for approximately 25% of its operating assemblies for use in carrying out certain self-test trouble-shooting procedures. These spares are not necessarily the optimum choices for selected spares stockage. Second, the presence of OVM is so critical to the performance of the OMTS in the situation where it must check out missiles fast enough to meet high firing rates, that very few spares can be removed without seriously degrading performance.

Figure 7 summarizes the results of a simulation of the OMTS checking out missiles at a high firing rate, with an OVM supply which decreases in an orderly way. The simulation process was dependent upon certain probability considerations, so that each circled point on Fig. 7 should be looked upon as the average outcome of a

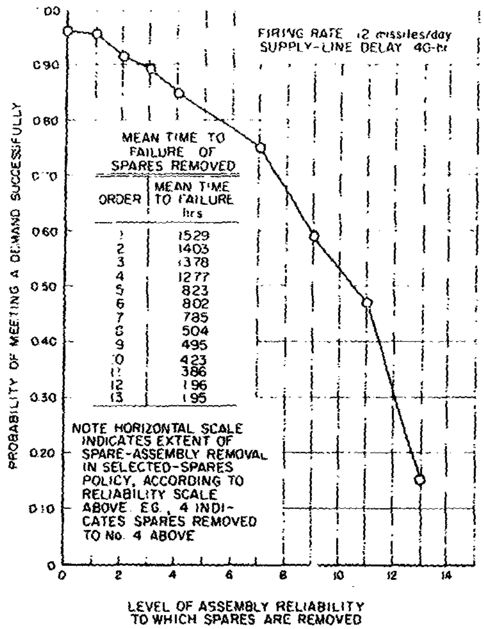

Fig. 7. Effect of Selected-Spares Removal on Checkout Reliability

large number (on the order of 2500) of experiments. The curve shows the effect on OMTS performance of removing first the most reliable spares, then removing in addition the second most reliable, etc. Performance drops off rapidly, indicating the extreme importance of OVM in this situation. It is unlikely that any selected-spares policy could be worked out for the OMTS which would not either seriously degrade the capability of the OMTS on the one hand, or, on the other, result in a spares stockage for the OMTS representing 80 to 90% of the total cost of OMTS operating assemblies.

3. *FMTS*. The Ordnance checkout station, the FMTS, requires spares for perhaps half of its assemblies for use in self-test procedures. It is believed that a selected-spares policy could be effectively employed on the remaining assemblies. Either the FMTS or the Ordnance D/S unit to which it is attached must have available one complete set of spares for the OMTS and the launching station in order to maintain the capability of supporting the *Sergeant* FAM Battalion by means of unit replacement. A policy of selected spares stockage for the system subassemblies seems reasonable and workable.

V. CONCLUSIONS

It is recommended that the *Sergeant* FAM Battalion be organized with one OMTS, which will be assigned to Headquarters and Service Battery. It is the engineering judgment of the Jet Propulsion Laboratory that the field-storage reliability of the *Sergeant* missile will be such as to make allocation of more than one OMTS per Battalion extravagant and of no advantage in system performance.

A continuing experiment to determine the field-storage reliability of the missile is recommended. Starting with the first Engineering-Model round, the program should continue through the Engineer-User Evaluation until the user is aware of all the ramifications of the field-storage problem, and until this reliability is established to the satisfaction of the user. The necessary record forms should be initiated immediately.

A policy of periodic checkout for the maintenance of the *Sergeant* Battalion's prescribed load of missiles should be established. Checkouts more frequent than necessary to maintain a given level of readiness reduce the maximum achievable reliability because of wear, a policy of performing too-frequent checkouts is uneconomical and dangerous. Performing the checkout immediately before firing is unnecessary and undesirable in any case; for "shoot and scoot" missions, such a checkout doubles the minimum total time for the operation.

The following policy on spare-parts stockage is recommended (1) 100% station OVM (electronics) for the launching station; (2) 100% station OVM (electronics) for the OMTS; (3) selected missile spares aboard the OMTS; (4) selected station spares for station assemblies not required in self-test procedures, aboard the FMTS; (5) 100% organic spares for launching-station and OMTS assemblies, associated with FMTS; (6) selected subassembly spares for all electronic assemblies in the weapons system.